An Efficient Compression Scheme for Colour Filter Array Images Using Estimated Colour Differences

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***Abstract*—Most consumer digital cameras capture colour images using a single light sensor and a colour filter array (CFA). The CFA allows only one colour of light (red, green, or blue) to reach the sensor at each pixel location. This results in a mosaic image being captured, where either a red, green or blue sample is captured at each location. The two missing colours must be interpolated from the surrounding samples in a process called demosaicking. The conventional approach to performing compression in these cameras is to first perform demosaicking and then compress the resulting full colour image with standard methods. However, recent work has attempted to compress the raw data captured by the sensor, with demosaicking being performed later. One challenge with this method (compression before demosaicking) is exploiting the correlation between the red, green and blue colour planes. Existing methods have used a modified YCbCr colour space conversion which is applied to groups of RGB samples captured at adjacent pixel locations. This results in poor performance around edges, where there is much lower correlation between the RGB samples. In this paper, we propose a new method of exploiting correlation between RGB samples when compressing CFA images. We use a 2D 5x5 linear filter to estimate the green value at each location where a red or blue sample is captured. We then compress the captured green samples, and two "chrominance" planes, which are obtained by taking the difference between the captured red and blue samples and the estimated green value at the same location. This results in much smoother chrominance signals than the modified YCbCr conversion used in previous work. Simulation results show that for different images, the proposed method results in bit rate reductions between 12-25% relative to the previous modified YCbCr conversion when compressing CFA images with JPEG.**

Keywords—image compression; colour filter array; digital cameras; colour spaces

I. Introduction

Consumer digital cameras typically capture colour information using a single light sensor and a colour filter array (CFA). The CFA allows only one colour of light (red, green or blue) to reach the sensor at each pixel location. This results in a mosaic image being captured, where either a red, green or blue sample is present at each pixel location. The two missing colours must be interpolated from the surrounding samples in a process commonly referred to as demosaicking.

The Bayer Pattern (Fig. 1) is the most commonly used CFA design, and it is used in the vast majority of the published work on demosaicking and single sensor cameras. Samples are captured in groups of four in the Bayer pattern, each group containing two green samples and one sample of red and blue.

The conventional approach to compressing images captured with a CFA is to first perform demosaicking and then compress the resulting full-colour image with standard methods (e.g., JPEG). Recent work has explored compressing the data captured directly, prior to demosaicking [1][2]. This approach has the advantage of smaller raw data size, since demosaicking expands the amount of data by a factor of three.

When an RGB image is compressed, a colour space conversion is almost always performed to de-correlate the colour channels, so they can be coded independently without loss of efficiency. The YCbCr space is most commonly used.

A CFA image compression method is proposed in [1], which starts with a modified YCbCr colour space conversion. Instead of being performed on red, green and blue samples captured at the same location (the standard case for an RGB image), the conversion is performed on a group of four Bayer pattern samples (Fig. 2). When calculating each luma sample (Y), the corresponding green sample is used together with the red and blue samples. When calculating the chroma samples (Cb and Cr), the average of the two green samples is used with the red and blue samples. After the modified YCbCr conversion, the chroma samples are placed into two rectangular arrays of Cb and Cr samples and they are compressed with standard JPEG. The Y samples are rotated 45 degrees to form a compact rhombus shape, which is compressed with a modified JPEG algorithm.

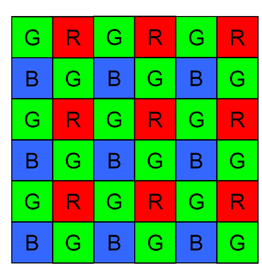

Figure 1: Bayer Pattern CFA

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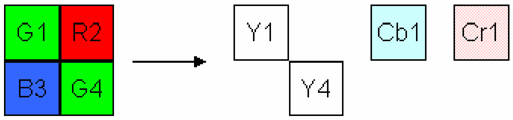

Figure 2: Modified YCbCr conversion

Another method for compressing CFA images is proposed in [2]. That method also starts with the modified YCbCr colour space conversion proposed in [1]. Two methods are proposed for creating rectangular arrays of the luma data, which allows the luma data to be compressed with standard JPEG. In the structure conversion method, the two luma samples generated from every Bayer cell are merged into a single column (Fig. 3b), creating a single luma array that has half the size of the CFA data. The structure separation method involves separating the even column and odd column luma samples into two arrays, each having size one quarter that of the CFA data (Fig. 3c).

A problem with the modified YCbCr conversion in [1] and [2] is that it is performed on RGB samples captured at different spatial locations. This produces poor results around edges, where the correlation between adjacent samples is much lower. Instead of producing chroma channels with smooth edges (as the standard YCbCr conversion does), the modified conversion tends to highlight edges in the chroma channels. This is illustrated in Fig. 4, which shows the Cb channel for a portion of the lighthouse image obtained with the standard YCbCr conversion performed on the full colour image, and the modified conversion performed on the CFA image. Note how the modified conversion generates a Cb channel containing strong edges, and thus high-frequency image content. This high-frequency content reduces the compression efficiency when a DCT based compression approach is used, as in JPEG.

In this paper, we propose an alternative method for exploiting the correlation between the RGB colour channels when compressing CFA images. To overcome the localization problem of the previously used modified YCbCr conversion, we use a low-pass filter to estimate the missing green sample at each red or blue location. We generate chroma channels by taking the difference between each red or blue sample and the estimated green value at the same location. The captured green channel is compressed, together with the two difference channels.

The rest of this paper is organized as follows. The proposed method is described in Section II. Results comparing the proposed method against the previous YCbCr conversion are presented in Section III. Finally, conclusions are given is Section IV.

II. Proposed Method

The problem with the modified YCbCr colour space conversion used in previous papers is the lack of localization. It attempts to exploit correlation between RGB samples captured at different positions. This works well in smooth regions of the image but breaks down at sharp edges, where there is far less correlation between adjacent samples. To overcome this problem, we estimate the green value at each

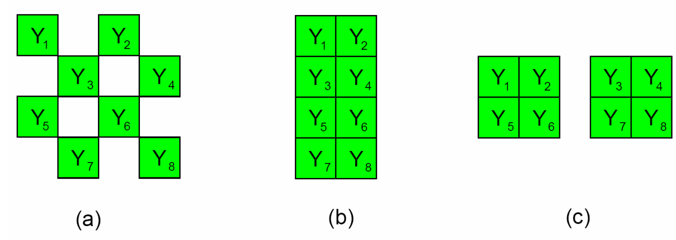

Figure 3: Luma arrangement methods proposed in [2]. (a) Original shape of luma samples (b) Structure conversion method (c) Structure seperation method

Figure 4: Cb channels of a portion of the lighthouse image. Original full colour image (left) and result of the modified YCbCr conversion used in [1]

red or blue pixel location. This estimated green sample should have high correlation with the red or blue value at the same location.

To keep the computational complexity low, a simple linear filter is used on the green channel to estimate the missing values. Consider the effect of sampling the green channel of an image with the Bayer pattern. The sampled green channel can be written in terms of the complete green channel, *G(i,j)*, as follows:

$$G_{sampled}(i,j) = \begin{cases} G(i,j) & (i+j) \text{ even} \\ 0 & \text{otherwise} \end{cases} . \quad (1)$$

The spectrum of the sampled green channel contains periodic replications of the spectrum of the true green channel [3], as shown in Fig. 5.

The original green channel can be recovered by filtering out the high frequency replications of its spectrum. To do this a 2D low-pass filter with a cut-off frequency of around 0.707π radians/sample is needed. After experimenting with different 2D low-pass filters we propose to use the following interpolation filter for estimating the missing green samples:

$$h = \begin{bmatrix} 0 & -1 & 0 & -1 & 0 \\ -1 & 0 & 6 & 0 & -1 \\ 0 & 6 & 16 & 6 & 0 \\ -1 & 0 & 6 & 0 & -1 \\ 0 & -1 & 0 & -1 & 0 \end{bmatrix} / 16 \quad (2)$$

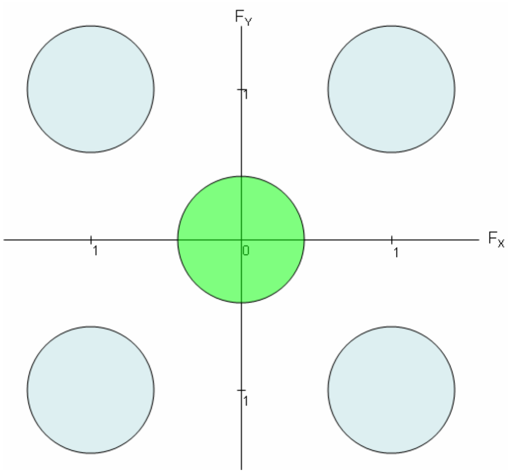

Figure 3: Periodic replication of the the green channel's spectrum when it is sampled with the Bayer pattern. The green circle indicates the frequency support of the original green channel, and the blue circles indicate the spectrum replicas found in the sampled green channel.

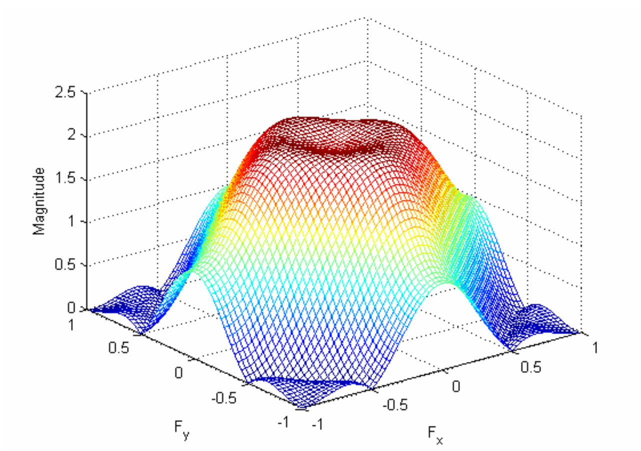

Figure 4: Frequency response of the proposed interpolation filter.

This filter has low computational complexity because it can be implemented with only bit-shift and addition/subtraction operations. The frequency response of the filter is shown in Fig. 6. Note how the filter provides high attenuation to the regions where the spectrum replication occurs.

After the missing green samples have been estimated, two "chroma" (colour difference) planes are generated by subtracting the estimated green value from each red or blue sample. For 8 bit data, the chroma channels are calculated as:

$$\begin{aligned} Cb &= \left(B - G_{est}\right)/2 + 128 \\ Cr &= \left(R - G_{est}\right)/2 + 128 \end{aligned} \quad (3)$$

In equation (3), the division by two is necessary to produce chroma channels that have the same bit depth as the original data. The addition of 128 shifts the range to prevent negative values.

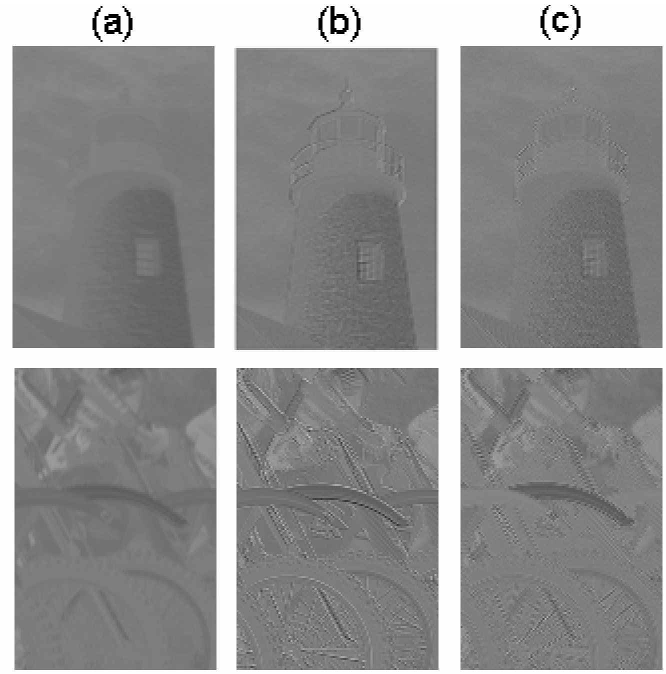

Figure 5: Cb channels of cropped portions of the lighthouse and bikes images. (a) Standard YCbCr conversion applied to full-colour image (b) Modifed YCbCr conversion in [1] (c) Proposed estimated colour difference

Our colour difference method produces chroma channels with less high-frequency content than the previous modified YCbCr conversion. This is illustrated in Fig. 7, which shows cropped portions of the Cb channel of lighthouse and bikes images. Note that the proposed method produces much smoother chroma channels than the modified YCbCr conversion, although not quite as smooth as the standard Cb channel of the full colour image.

The captured green samples are compressed, along with the two colour difference signals. Note that the estimated green values do not need to be compressed, as they can be generated at both the encoder and decoder from the captured green samples using the interpolation filter.

Our colour difference scheme could be used together with any of the methods for compressing the luma samples in [1] or [2], with the green samples treated as the luma channel. Here, we use the structure conversion method in [2], as it has the advantages of using standard JPEG for compression, and it requires three channels to be compressed (rather than four for the structure separation method).

III. Results

The testing procedure used consists of the following steps, starting with a full colour RGB image:

1) Sub-sample the RGB image with the Bayer pattern to form a CFA image.
2) Apply a colour conversion to the CFA image (either the proposed scheme or the previous modified YCbCr conversion).
3) Compress the three colour channels with JPEG
4) Decompress
5) Reverse the colour conversion to restore the CFA image

Figure 7: Test images: parrots, lighthouse and bikes.

6) Apply demosaicking to generate a full-colour image

We measure the quality of the final demosaicked image relative to the initial full colour image. The quality measure used is the composite peak signal-to-noise ratio (CPSNR). The CPSNR is calculated like the standard PSNR, only with the mean-square error averaged across the red, green and blue colour channels [2]. The demosaicking method used for generating the final full colour images is the popular adaptive method by Hamilton and Adams in [4].

We provide results for three images from the Kodak image set, parrots, lighthouse and bikes (Fig. 8). The parrots image has relatively little high-frequency content, lighthouse contains moderate amounts of high-frequencies, and bikes has a lot of high-frequency content.

Rate-distortion curves for the three images are shown in Fig. 9, using each colour representation (the proposed estimated colour differences, or the modified YCbCr). For all three images, there is substantial gain in using the proposed method relative to the previous YCbCr conversion. The average CPSNR gains are about 0.7 dB, 1.0 dB and 1.2 dB for the parrots, lighthouse, and bikes images respectively. This corresponds to bit rate reductions of about 12%, 20% and 25% for the three images. The results show that the proposed estimated colour difference method provides larger gains in performance for images with more high-frequency content. This is expected, as the modified YCbCr conversion does not work well in high-frequency regions and the proposed method was developed to help overcome that problem.

IV. Conclusions

In this paper we propose a new method for compressing CFA images based on estimating colour differences for the captured red and blue samples. A 2D low pass filter is used to estimate the green channel's value at each red or blue location, and chroma planes are generated by subtracting the estimated green value from the red or blue sample. This produces substantially smoother chroma planes than the previously used modified YCbCr colour space conversion, resulting in up to 25% improvement in compression efficiency when JPEG is used to compress the three colour planes of a CFA image.

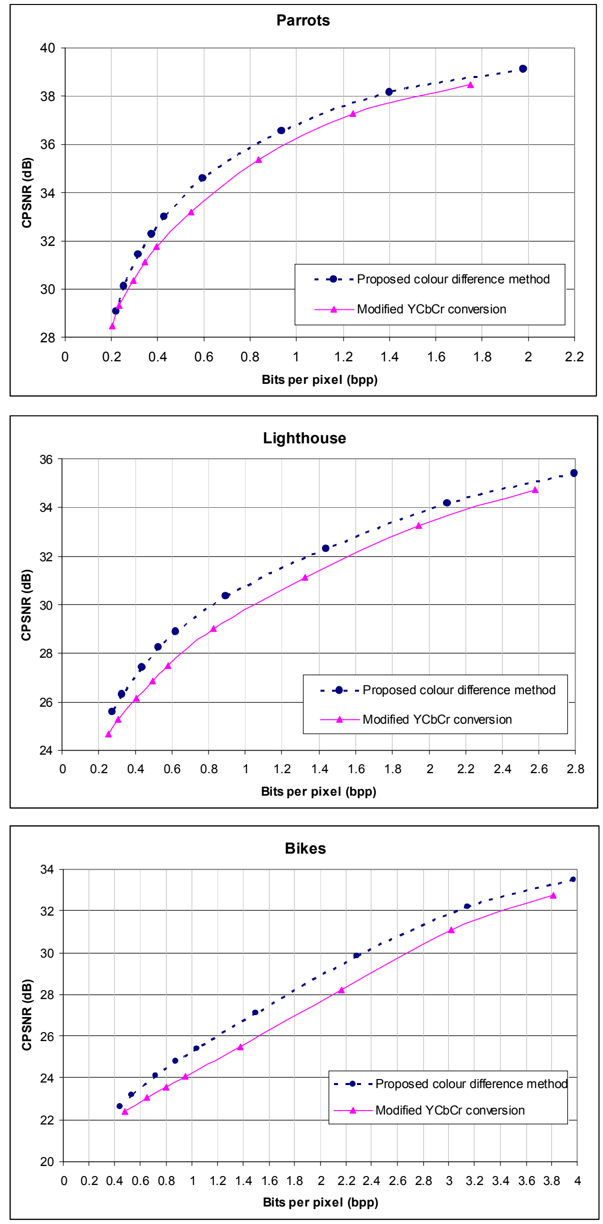

Figure 6: Plots of CPSNR vs. bit-rate for the three test images.

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